Al-Rafidain Engineering Journal (AREJ) Vol.28, No.1, March 2023, pp. 125-132

Mitigationof Total Harmonic Distortion and Power Factor Improvement Based PVSTATCOM

Ammar A. A. AL-Ani* **Majid S. M. Al-Hafidh****

amar.a.abdlhamed@tu.edu.iq alhafidms@uomosul.edu.iq

*Electrical Engineering Department, Collage of Engineering, University of Tikrit, Tikrit, Iraq

**Electrical Engineering Department, Collage of Engineering, University of Mosul, Mosul, Iraq

Received: 2022-07-27 Received in revised form: 2022-09-01 Accepted: 2022-09-27

ABSTRACT

The increasing use of power-electronics equipment has led to various power quality problems, including current wave distortion . Also, renewable energies (solar and wind energy) are increasingly used to supply part of the electrical load,especially Photovoltaic (PV). The use of PV-STATCOM achieves many benefits, among them mitigating the distortion of the current wave , improving the power factor , compensatingthe active and reactive power , and improving the system 's stability. This paper deals with mitigating current wave distortion and improving power factors together. This paper designs a STATCOM Modular Multilevel Converter (MMC) controller with combines reactive power compensation and harmonicsmitigation for linear load and proposed a simulated six pulse three-phase rectifier as nonlinear load. The pulses gate of theswitches of the sub -modular converter has been obtained by using a proportional -integral (PI) current controller with d-q references. The time-domain-based reference method for the reference current extraction is adopted. MMCSTATCOM were simulated with proposed nonlinear model loads in MATLAB . The simulation result showed that the developed MMCSTATCOM minimizes the total harmonic distortion below the standards recommended by the IEEE.

Keywords:

PV-STATCOM, Total Harmonic Distortion mitigation, Power Factor improvement, Non-linear Load.

1. INTRODUCTION

Energy demand and environmental degradation are major challenges facing countries around the world. Renewable energy sources have shown attractive prospects. Renewable energy sources can be used to generate energy especially sunlight , wind , or biomass . The pollution from these energy products is much less than that from other generation methods and they can be used as environmentally friendly sources[1].

Further, in recent years, there has been growing concern about the introduction of current harmonics due to the use of nonlinear loads such as power electronics devices like rectifiers[2]. In order to connect the renewable sources to the grid system, a three-phase DC to AC conversion procedure is required. Three-phase alternating current must be synchronized with the network in voltage, frequency, and phase parameters. Renewable resources are connected to the grid system by using PV-STATCOM[3-5].

Frederico T. Ghettietal.(2011) presented a study of an MMC-based Shunt active power filter. Each MMC stage was built with eight sequentially connected subunits .The simulation results reveal that the MMC is able to accurately track reference compensating currents[6].Basil M. Saied , and Basim M. A. Anwar (2015) address a key aspect of improving the quality of electric power to tackle the distortion due to the widespread use of power electronics systems in nonlinear loads in general , as well as addressing loads of influence on power factors. The proposed system has the ability to control the reactive power flow in power schemes and also reduce harmonics at the same time by compensating all of the imaginary parts of the load current and harmonics. The results of the analysis and representation of the system have the ability and efficiency in improving both power factor and shape of the supply current wave forms power within allowable standards for linear and nonlinear loads[7]. V . Sridhar, S . Umashankar (2017) provided a comprehensive review of Cascaded H-Bridge Adapters(CHB). Explanation of the review controls PV - STATCOM . Furthermore ,the authors highlight the design of multi-levelPV-

STATCOMin a high -power application using two -tiered STATCOMPV . In addition, the review recommends the use of CHB for net worked applications and multi-level switches[8]. Epameiondas Kontos et al (2017) studied high harmonic voltage and current attenuation. The study used STATCO M multi -level modular transformer type . The harmonics were softened by using the MMC as the active filter. The authors experimented with and verified the current and selective harmonics detection method using the prototype developed by MMC [9].

Xuefeng Ge et al. (2017) introduced an H-Bridge STATCOM in a cascade structure .This STATCOM is configured at low amplitude with flexible third harmonic voltage control .The authors stated that their architecture reduces the peak voltage of the capacitor as a result of the injected capacitive interaction . Thus , switching losses are reduced [10].

Akshay D. Kadu et al.(2017) used a direct current control approach with a conventional transformer for harmonic attenuation as well as power factor improvement. The paper explains the basic process of STATCOM DC control for both linear and non-linear load. The authors stated that the indirect current control approach is less complex compared to other methods due to the rapid response and precise nature of the direct current control approach[11].

A. A. Imam (2020) introduced Shunt Active Power Filters (SAPF) based on PQ and DQ theory and compared them under different loading conditions . PWM hysteresis and current control techniques are used to generate the gate-pulse signals of the SAPF converter. Simulink's results confirmed the efficacy of two methods in harmonic mitigation and energy quality improvement[12].

Mahmood T. Al khayyat et al.(2021) introduced (SAPF) based on PQ theory with DC junction voltage regulation by a PI controller. The gate pulses regulating voltage source switching (VSI) switches are obtained by controlling the hysteresis current. The simulation resultsshow compensation for the current distortion of the source under different loading conditions[5].

In previous research, the design and characteristics of the appropriate STATCOM were studied to be added to the feeder ring of thecity of Mosul [13]. In another study , the effect of adding an energy storage device on compensating the reactant and active capacity in the transient state was studied [14-15]. Also, the best way to improve the stability of the power system was studied by using synchronous reactance power compensator [16].

In this work, a proposed nonlinear load modeling for a six pulse converter with a simple circuit is considered . The active filter cancels out the load current's harmonic content and compensates for the load power factor. The capacitor voltages were controlled and balanced using a sorting technique that is suitableforactive power filter applications.

The gate pulses of the transformer switch sub -module were obtained by incorporating an integrated proportional(PI) current controller with d-q references. A detailed STATCOMMMCS imu link model was used to realize the developed MMC. The outcome can be summarized into five folds : stabilization of the DC -side voltage , reducing voltage fluctuation ,faster response speed, reducing the circulating current, and finally better compensation effect. Also, a proposed nonlinear model load was developed and simulated in MATLAB. The results indicate that the MMC STATCOM controller reduces THDi to an acceptable standard level (within the standard specification) in addition to improving the power factor of the system used.

2. RESEARCH METHODOLOGY

Excessive use of power electronics equipment in modern life and industry has, at present , resulting in high levels of harmonics which issues many power quality problems .On the other hand, reactive power compensation is necessary for power factor correction that eliminates penal ties for reactive power reduces kVA demand , and reduces power loss generated in(power system components).PV-STATCOM is the modern way to deal with the use of renewable energy as distributed generation in the grid for active and reactive power control, voltage stabilization for wake-up buses, and other tasks.

In this work, we try to combine harmonic Mitigation in grids and power factor correction by PV - STATCOM as a smart inverter to reach the limit of IEEE standard 519-1992(5%) and get a suitable power factor too using the proposed Simu link model for six pulse converter as non linear load . Current Control Technique with Synchronous reference frame also called dq control. It uses a frame transformation reference module that rotates synchronously with the grid voltage vector .Thus ,the control variables are considered as dc values .As a result of the satisfactory behavior associated with the regulation of dc variables the dq control structure is normally associated with Proportional Integral (PI) controllers with linear and a proposed nonlinear load and associated treatment.

3. PROPOSED SYSTEM

Fig.1 is used to realize the research idea. The figure consists of several parts: a Modular Multilevel Converter, linear and non-linear loads, and a simple power system consisting of a generator with Source impedance . A proportional- integral (PI) current controller with d-q references is in order to get thegate pulses for sub modules controlled by a level shift pulse width modulator(LSPWM).

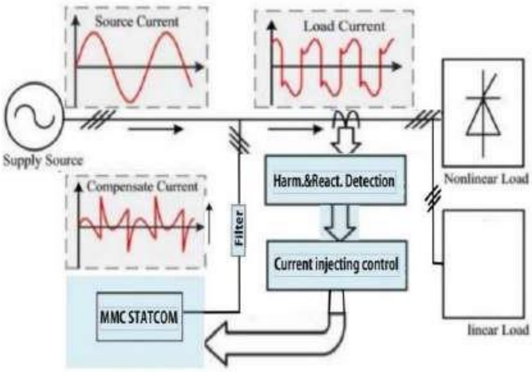

Fig.1 The principle block diagram torealizethe researchidea

3.1. Modular Multilevel Converter

The MMC has recently focused on as a substitute solution to conventional multi level converters in intermediate voltage claims . Fig. 2 represents the structure of MMC,which has the sub -module (SM) configurations. Normally, the sub-modules contain specific components. Table (1) illustrates these components.

Table (1) The sub-module components

Components	Count
Diode	2
Insulated-GateBipolar Transistor (IGBT)switches	2
Capacitor	1

In the three -phase system , six arms each are constituted by a number of SM . However, modular converters mainly have proper implantation over other multilevel structures .Not only Modularity but also scalability, and performance compatibility are considered advantages of common DC sources [17].

Many features related to MMC like the capability of a transformer, low expenses, robustness fault tolerance ,high reliability ,and good output wave forms quality made its topology suitable for various medium/high voltage applications [18,19].

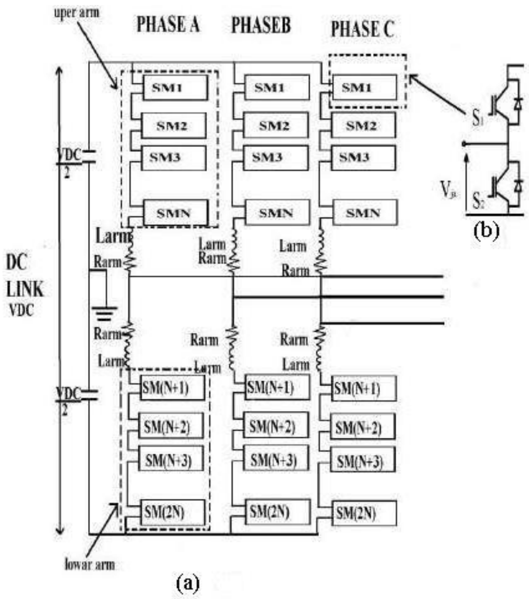

Fig. 2 Block diagram of MMC(a)Three phase block diagram.(b)Half-bridgeSMconfiguration.

3.2. Non-Linear Load

Static power converters are the main nonlinear (harmonic -producing) loads in power distribution systems. They are widely used for various applications with a wide range of power ratings . For the six pulse converter to have a dc load current a series inductance adds to the load to insure the pure dc current load fig . 3. The diode and input alternative line current is shown in fig. 4 .The analysis of the Fourier series in any phase of the ac line is given in equation(1)

$$I(t)=\frac{2\sqrt{3}}{\pi}I_{d}\left[\cos(wt)-\frac{1}{5}\cos(5wt)+\frac{1}{7}\cos(7wt)-\frac{1}{11}\cos(11wt)+\frac{1}{13}\cos(13wt)\cdots\right] \quad \ldots\ldots(1)$$

The resulting frequencies in the six pulse converter are given in equation(2).

$$h=6*k\pm1 \qquad (k=1,2,3,4) \quad \ldots\ldots(2)$$

Therefore the affecting harmonics in the system are 5, 7, 11, 13, 17, and 19 [20, 21]. A model was designed to give these harmonics , and in order to take into account the possibility of changing the proportion of harmonics, the model was designed to give variable values for harmonics as illustrated in fig.5.

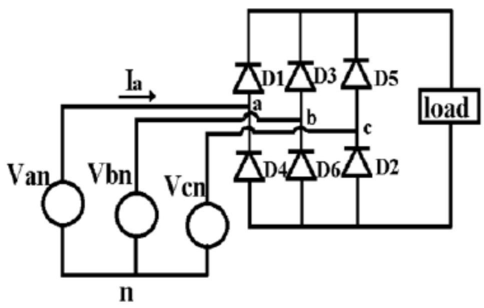

Fig.3Threephasesixpulserectifier.

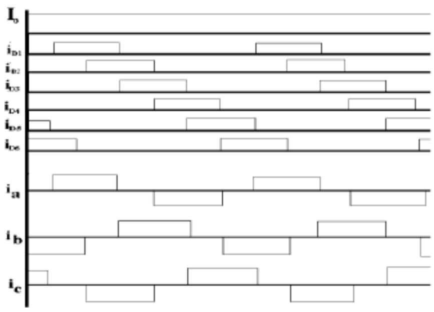

Fig.4 Three phase rectifier currentswithfiltered at output.

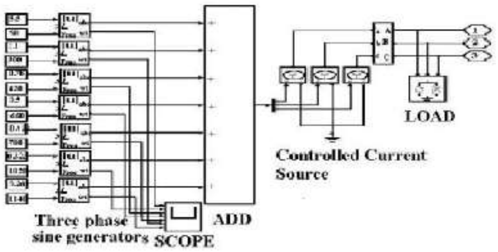

Fig.5 ProposalSimulinkmodelofsix pulseconverter.

3.3. Power System

Fig . 7 illustrates the model to realize the research idea , which consists includes (i) a three -phase AC voltage source,(ii) the proposed design for a three-phase nonlinear load, and (iii) an MMCPV -STATCOM converter. Figure(6) shows

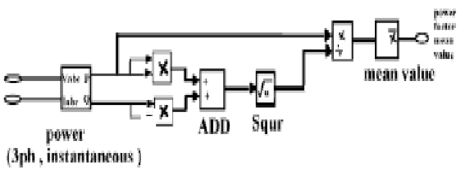

Fig.6 Simulink for power factor calculation(P/S)

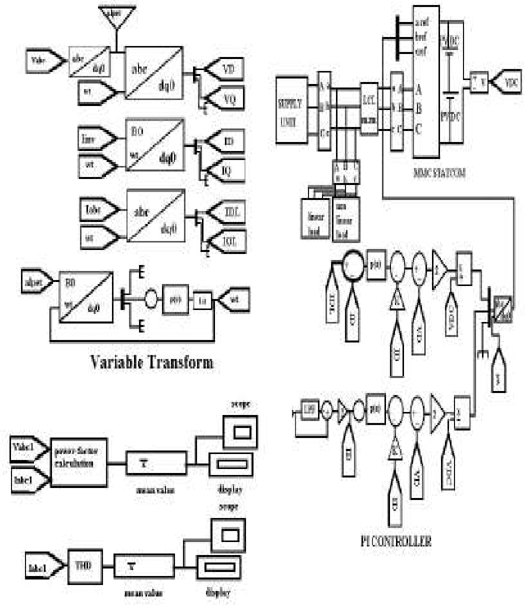

Fig.7 Simulink model of the Research idea.

4. RESULTS AND DISCUSSIONS(10 PT)

The effectiveness of the control procedure method under the specified configuration is performed through a system simulation using the MATLAB of the developed MMC STATCOM . The parameters of the simulated simulation , are itemizedin Table 2. The effectiveness of the analyzed PV -MMCSTATCOM against harmonic current limination and power factor correction were examined under linear and non linear balanced load conditions.

Table 2. The parameters of the system

Parameter	Value
AC rms source voltage	400 volt
System Frequency	60Hz
Impedance of the Source RS=0.1Ω, LS=10mH	
The impedance Filter Rs=0.0Ω,LS= 1.0mH	
Voltage DC bus(PV-ARRAY)	800Volt
The frequency of switching	2KHz
n(number of SM per arm)	17
for100%loading KP(Id)	1.2
for100%loading Ki(Id)	2
for100%loading Kp(Iq)	0.2
for100%loading Ki(Iq)	0.8

Fig.8 highlights the system with nonlinear load along with the distorted three-phases ource current (Isabc). In addition to the nonlinear load current (

Il abc)waveforms . The figure shows distortion in the source current as a consequence of the non linearity behavior of the load. Fig. 9 shows the power factor measurement recorded at 0.69 without PV-STATCOM.

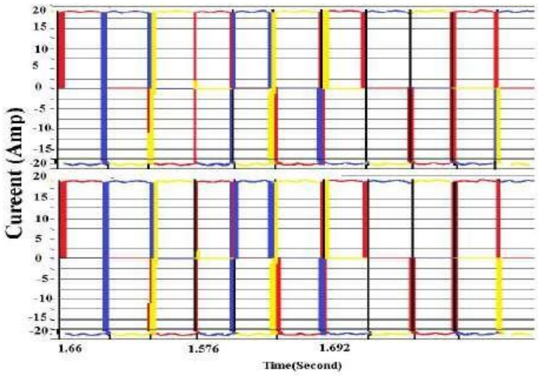

Fig. 8 Without PV- STATCOM

(a) sourcecurrent; (b)loadcurrent

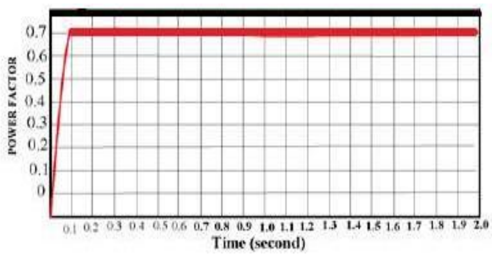

Fig.9 Power factor without PV-STATCOMAs

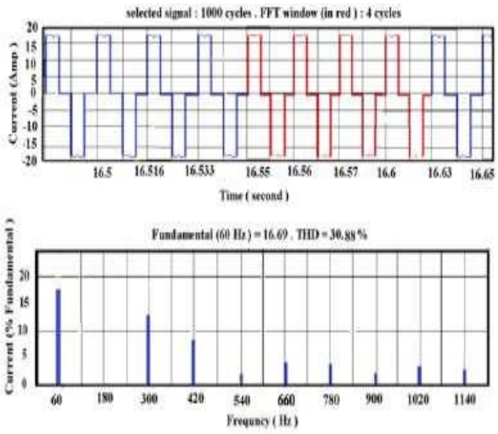

Fig.10 Source current FFT analysis without PV-STATCOM

First of all the reactive power compensator for power factor correction is obtained by the d-q theory transforming the variables to direct and quadratic one .To generate the compensation reference current (after driving the controller obtained from mathematics model doing for that objected) to transform the reference current to actual one by level shift pulse width modulator (LSPWM) for MMCPV-STATCOM

.On the other side extracting the harmonic reference current from the load current based on the same DQ theory is used as in figure (11).

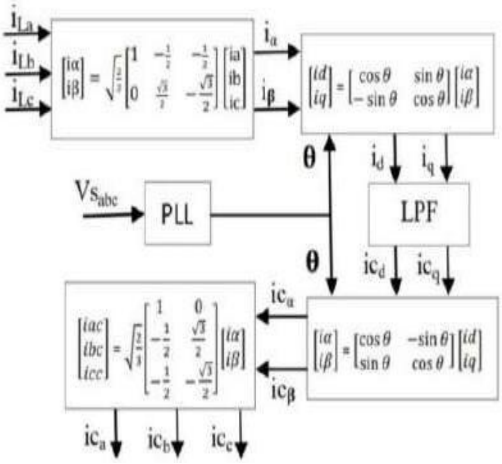

Fig.10 Source current FFT analysis without PV-STATCOM.

First of all the reactive power compensator for power factor correction is obtained by the d-q theory transforming the variables to direct and quadratic one .To generate the compensation reference current (after driving the controller obtained from mathematics model doing for that objected) to transform the reference current to actual one by level shift pulse width modulator (LSPWM) for MMCPV-STATCOM

.On the other side extracting the harmonic reference current from the load current based on the same DQ theory is used as in figure (11).

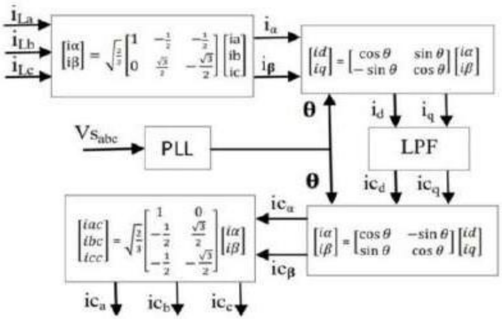

Fig.11 DQ theory for PV STATCOMPI controller.

The transformation of non -linear load current from a-b-c coordinates to α- coordinates is done by the well -known Clarke and park transformation. Then , theα- coordinates are further transformed to d-q coordinates.

The phase angle (theta) and frequency of source voltage for the d-q transformation was obtained through a Phase-Locked Loop (PLL).The d-q rotating reference frame is utilized for the process of obtaining the fundamental and harmonic currents. Further, the resultant current was transformed to the DC value and the harmonic component was transformed to the AC component . A high order Low-Pass Filter (LPF) was used to filter the AC components. The transformation of the currents from two - phase synchronous frame d-q into two- phase stationary frame α is accomplished by an inverse transformation. In the end, extracted currents back to the original frame a-b-c from two phases stationary frame α and obtains the compensation reference currents ica, icb, and icc. Adding the reference compensated current for reactive power compensated to reference currents for harmonic mitigation extraction references to combined the reference for controlling the injected control current by PI controller to have effected low THD fact or with standard and suitable power factor too.

The PI controllers for direct current reference and PI controller for quadratic reference affected to control the injecting current to correct the power factor and mitigate the harmonic withstand. The try and error method is used for a specific load . Fig .12 show the current Total Harmonics Distortion (THDi) mitigated. Meanwhile, the performance of the compensator to correct the power factor is justifiedat 0.89 asshownin Fig.13 with the PI parameter indicated as mentioned in Table 2.

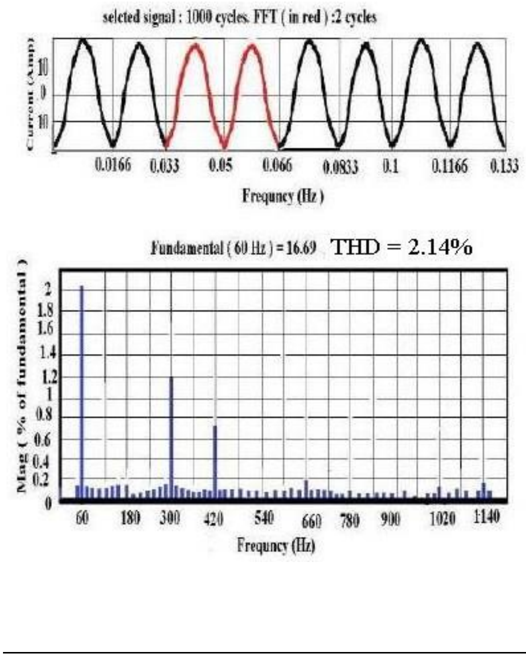

Fig.12 Harmonic mitigationby PV – STATCOMcontroller.

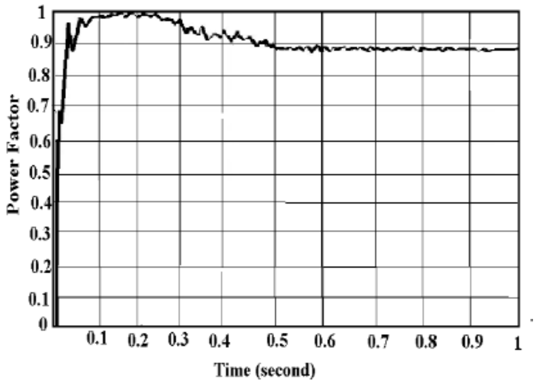

Fig .13 Correction powerfactorby PV _ STATCOM.

5. CONCLUSION (10 PT)

The increasing use of non -linear loads has led to increasing problems in power systems. The challenges of climate change have also led to the increasing use of renewable energies .Currently ,PV- STATCOM is used to deliver the seenergies to the power system.

PV - STATCOM can be used for various purposes including mitigating current wave distortion , improving power factor, compensating active power and reactive power , and improving system stability . The current research addresses the use of PV -STATCOM . This paper deals with mitigating current wave distortion and improving power factors together.

A non -linear load giving harmonics similar to a 6-pulse converter is represented, with the values of these harmonics changing . A simplified system was used to realize the idea of research .Many cases were analyzed, and one case was included in the research . The simulation analysis results show that the PV - STATCOM with PI controller significantly minimizes the current harmonics below the allowable limits of the IEEE standard as well as improves the power factor to an acceptable value. The FFT spectrum show that the THDi was reduced from 30.88% to 2. 14%.and a power factor improved from 0.69 to a value of 0.89.

REFERENCES

[1] M. G. Villalva, J. R. Gazoli, and E. Ruppert Filho, “Comprehensive approach to modeling and simulation of photovoltaic arrays,” IEEE Transactions on power electronics, vol. 24, no. 5, pp. 1198–1208, 2009.

[2] M. Waheed, A. A. A. al Bakry, F. N. Saeed, and others, “Harmonic reduction in IEEE-3-bus using hybrid power filters,” in IOP Conference Series: Materials Science and Engineering, 2021, vol. 1105,

no. 1, p. 012012, doi:10.1088/1757-899X/1105/1/012012.

[3] A. Luo, C. Tang, Z. Shuai, J. Tang, X. Y. Xu, and D. Chen, "Fuzzy-PI-based direct-output-voltage control strategy for the STATCOM used in utility distribution systems," IEEE Transactions on Industrial Electronics, vol. 56, no. 7, pp. 2401–2411, 2009.

[4] J. M. Carrasco et al., "Power-electronic systems for the grid integration of renewable energy sources: A survey," IEEE Transactions on industrial electronics, vol. 53, no. 4, pp. 1002–1016, 2006.

[5] M. T. Alkhayyat, M. Y. Suliman, and F. F. Aiwa, "PQ & DQ based shunt active power filter with PWM & hysteresis techniques," Przegląd Elektrotechniczny, vol. 97, 2021, doi:10.15199/48.2021.09.17.

[6] F. T. Ghetti, A. A. Ferreira, H. A. Braga, and P. G. Barbosa, "A study of shunt active power filter based on modular multilevel converter (MMC)," in 2012 10th IEEE/IAS International Conference on Industry Applications, 2012, pp. 1–6.

[7] B. M Saied and B. MA Anwar, "Using Static Reactive and Distortion Power Compensation System to improve The Quality of The AC Supply," Al-Rafidain Engineering Journal (AREJ), vol. 23, no. 4, pp. 124–142, 2015.

[8] V. Sridhar and S. Umashankar, "A comprehensive review on CHB MLI based PV inverter and feasibility study of CHB MLI based PV-STATCOM," Renewable and Sustainable Energy Reviews, vol. 78, pp. 138–156, 2017.

[9] E. Kontos, G. Tsolaridis, R. Teodorescu, and P. Bauer, "High order voltage and current harmonic mitigation using the modular multilevel converter STATCOM," Ieee Access, vol. 5, pp. 16684–16692, 2017.

[10] X. Ge and F. Gao, "Flexible third harmonic voltage control of low capacitance cascaded H-bridge STATCOM," IEEE Transactions on Power Electronics, vol. 33, no. 3, pp. 1884–1889, 2017, doi:10.1109/ TPEL.2017.

[11] A. D. Kadu, P. Debre, R. Juneja, and N. Pande, "Application of STATCOM for harmonic mitigation and power factor improvement using direct current control technique," in 2017 Second International Conference on Electrical, Computer and Communication Technologies (ICECCT), 2017, pp. 1–4.

[12] A. A. Imam, R. Sreerama Kumar, and Y. A. Al-Turki, "Modeling and Simulation of a PI Controlled Shunt Active Power Filter for Power Quality Enhancement Based on P-Q Theory," Electronics, vol. 9, no. 4, 2020, doi: 10.3390/electronics9040637.

[13] M. S. M. Al-Hafidh, "Simulation of a Static Synchronous Compensator in the 132KV Mosul Ring System," PHD Thesis ,University of Mosul, Iraq, 2006.

[14] D. A. Al-Nimma, M. S. Al-Hafid, and S. E. Mohamed, "Simultaneous active and reactive power control of ESTATCOM for improving mosul city ring system," in 2012 First National Conference for Engineering Sciences (FNCES 2012), 2012, pp. 1–6.

[15] D. A. Al-Nimma, M. S. Al-Hafid, and S. E. Mohamed, "Voltage profile improvements of Mosul city ring system by STATCOM reactive power control," in International Aegean Conference on Electrical Machines and Power Electronics and Electromotion, Joint Conference, 2011, pp. 525–530, doi: 10.1109/ACEMP .2011.6490654

[16] M. A. Jirjees, D. A. Al-Nimma, and M. S. Al-Hafidh, "Voltage stability enhancement based on voltage stability indices using FACTS controllers," in 2018 International Conference on Engineering Technology and their Applications (IICETA), 2018, pp. 141–145.

[17] A. Lawan, H. Abbas, J. Khor, and A. A. Karim, "Dynamic performance improvement of MMC inverter with STATCOM capability interfacing PMSG wind turbines with grid," in 2015 IEEE Conference on Energy Conversion (CENCON), 2015, pp. 492–497.

[18] Z. Liu, X. Hu, and Y. Liao, "Vehicle-grid system stability analysis based on norm criterion and suppression of low-frequency oscillation with MMC-STATCOM," IEEE Transactions on Transportation Electrification, vol. 4, no. 3, pp. 757–766, 2018.

[19] J. V. M. Farias, A. F. Cupertino, H. A. Pereira, S. I. S. Junior, and R. Teodorescu, "On the redundancy strategies of modular multilevel converters," IEEE Transactions on Power Delivery, vol. 33, no. 2, pp. 851–860, 2017.

[20] Y. S. Waykole, "Comparative Analysis of 6 and 12 Pulse STATCOM," International Research Journal of Engineering and Technology (IRJET), vol. 7, no. 9, pp. 1117-1122, 2020.

[21] B. Gultekin et al., "Design and Implementation of a 154-kV \backslashpm 50-Mvar Transmission STATCOM Based on 21-Level Cascaded Multilevel Converter," IEEE Transactions on Industry Applications, vol. 48, no. 3, pp. 1030–1045, 2012.

تخفيف التشوه الكلي للتوافقيات وتحسين عامل القدرة باستخدام المعوض الكهروضوئي (STATCOM)

عمار عبد الجواد العاني*
amar.a.abdihamed@tu.edu.iq

ماجد صالح الحافظ**
alhafidms@uomosul.edu.iq

*كلية الهندسة - قسم الهندسة الكهربائية - جامعة تكريت – تكريت - العراق
**جامعة الموصل - كلية الهندسة - قسم الهندسة الكهربائية - موصل - العراق

تاريخ الاستلام:2022-07-27 استلم بصيغته المنقحة:2022-09-01 تاريخ القبول:2022-09-27

الملخص

ان الاستخدام المتزايد لمعدات الكترونيات القدرة في منظومات القدرة الكهربائية اثرسلبا" على جودة القدرة من خلال تشوه موجتي التيار والفولتية. ان استخدام الطاقات المتجددة (الطاقة الشمسية وطاقة الرياح) لتجهيز جزءا" من الحمل الكهربائي كان له نفس التاثير وخصوصا" الخلايا الشمسية , بما في ذلك تشوه موجة التيار. ويتم ايضا" استخدام الطاقات المتجددة (الطاقة الشمسية وطاقة الرياح) بشكل متزايد لتزويد جزءا" من الحمل الكهربائي, وخاصة خلايا الطاقة الشمسية. ان استخدام معوض القدرة الساكن الكهروضوئي يحقق فوائد عديدة منها تخفيف تشوه موجة التيار وتحسين عامل القدرة وتعويض القدرة الفاعلة والمتفاعلة, فضلا" عن تحسين استقراريه المنظومة.

يتناول هذا البحث طرائق تخفيف تشوه التيار وتحسين عامل القدرة. ان تصميم وحدة تحكم موثوقة لتخفيف تأثير توافقيات التيار , فضلا عن عملها كمعوض للقدرة التفاعلية يعد ضروريا لمنظومات القدرة الحديثة. لقد تم تصميم معوض متعدد المستويات لتنفيذ ما ذكر في اعلاه للأحمال غير الخطية. كما تم توليد نبضات القدح باستخدام مسيطر تيار (تناسبي – تكاملي) بمحاذاة المتجه المرجع (العمود- المباشر) , حيث تم اعتماد الأسلوب المرجعي المستند للمجال الزمني لأيجاد مرجع التيار. كما وتم بناء وتمثيل النظام المقترح مع الحمل غير الخطي باستخدام برنامج Matlab *. لقد بينت نتائج التمثيل أن المعوض المصمم قلل التشوه وأنها أصبحت ضمن معايير* IEEE *القياسية.*

الكلمات الداله :

التشوه الكلي للتوافقيات, تحسين عامل القدرة, الحمل غير الخطي, معوض القدرة الساكن الكهروضوئي.